NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

TECHNICAL NOTE 3354

GUST EXPERIENCE OF A HELICOPTER AND AN

AIRPLANE IN FORMATION FLIGHT

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SUMMARY

A single-rotor helicopter and an airplane have been flown in formation in rough air for the purpose of measuring and comparing the responses of the aircraft to gusts. Rough-air flights were also made by the helicopter alone at several airspeeds over the same ground path.

The results indicated a somewhat greater gust alleviation for the helicopter than for the airplane over the speed range investigated. In addition, a substantial effect of speed on the normal accelerations of the helicopter due to gusts was observed.

INTRODUCTION

Rotary-wing design specifications, both military and civil, require that load factors due to an arbitrary gust be considered. The response of a lifting rotor to gusts is difficult to predict analytically, however, because of the transient nature of the disturbance and the large number of variables involved. For example, a rigorous mathematical approach would probably need to include such items as transient blade flapping, blade flexibility, induced-velocity changes, and vertical motion of the helicopter. Simplified methods may provide adequate answers for design purposes, but require experimental verification before they can be used with confidence.

A great deal of information is available concerning the effects of gusts in terms of the response of fixed-wing aircraft (see ref. 1). Therefore, one approach to the problem is to fly an airplane and a helicopter under the same conditions of turbulence and to compare the measured ratios with the calculated ratios of the normal accelerations. Accordingly, a single-rotor helicopter and an airplane of comparable size and suitable speed range (fig. 1) were flown side by side in rough air, and the normal accelerations of each were measured and compared with some simply calculated predicted values.

Inasmuch as this investigation revealed an effect of airspeed on helicopter accelerations which was not in accord with the simple analytical approach, additional flights were made in which the helicopter was flown in gusty air at several different airspeeds over the same ground path.

SYMBOLS

Δa_n normal-acceleration increment, g units

C_L airplane lift coefficient, $\dfrac{L}{\frac{1}{2}\rho S V^2}$

C_T helicopter thrust coefficient, $\dfrac{T}{\rho \pi R^2 (\Omega R)^2}$

L lift, lb

R rotor blade radius, ft

S wing area, sq ft

T thrust, lb

U vertical gust velocity, fps

V forward velocity, fps

W weight of aircraft, lb

α angle of attack of helicopter rotor or airplane wing, radians

ρ air density, slugs/cu ft

Ω rotor angular velocity, radians/sec

METHODS AND TESTS

Two flight procedures were used to obtain the comparative rough-air accelerations of the helicopter and the airplane. One method was to fly the two aircraft in formation at an airspeed of 80 miles per hour; in the other instance, the airplane, flying at 140 miles per hour, overtook

and passed the helicopter which was flying at 40 miles per hour. The tests consisted of three formation flights and two overtaking maneuvers. All these tests were conducted during a period of about 40 minutes in clear, rough air at altitudes between 600 and 1,000 feet.

Standard NACA instruments were used to record the airspeed and normal acceleration (measured near the center of gravity) of each aircraft. The peak values of normal acceleration were read to the nearest 0.01g for the helicopter and 0.02g for the airplane, and are shown in table I as incremental values from a 1.0g reference.

RESULTS AND DISCUSSION

In order to provide a basis for comparing the accelerations encountered by the test airplane and helicopter, the response of each to a unit vertical gust was calculated by using the elementary approach which considers the gust to produce only an angle-of-attack change and neglects any alleviation factors. The relations used were

$$\frac{\Delta a_n}{U} = \frac{1}{2} \frac{dC_L}{d\alpha} V\rho \frac{S}{W} \tag{1}$$

for the airplane and

$$\frac{\Delta a_n}{U} = \frac{dC_T}{d\alpha} \frac{(\Omega R)^2}{V} \rho \frac{\pi R^2}{W} \tag{2}$$

for the helicopter. The derivation of equation (1) is given in reference 1, and equation (2) may be derived in an analogous manner by assuming the thrust equal to the weight and the change in angle of attack equal to U/V.

The resulting curves, shown in figure 2, are based on a wing loading of 14 pounds per square foot for the airplane and a disk loading of 2.8 pounds per square foot for the helicopter. Because the slope $dC_T/d\alpha$ is not constant but increases almost linearly with forward speed (ref. 2), the values of $\Delta a_n/U$ shown for the helicopter are approximately constant at speeds above 40 miles per hour. Below this speed this simple approach becomes inadequate since the value of $dC_T/d\alpha$ becomes increasingly dependent on variables which are affected by the magnitude of the gust; therefore, the lower part of the curve is indicated by the dashed line. However, a good starting point is provided for comparison of the ratios of normal acceleration at speeds common to this particular airplane and helicopter.

The frequency distributions of the acceleration increments in table I are shown in figures 3 and 4 in terms of the average number of flight miles required to equal or exceed a given value. The ratio of the measured accelerations of the helicopter and airplane at any given distance (figs. 3 and 4) may be compared with the calculated values of figure 2. At 80 miles per hour, for example, the predicted ratio of helicopter to airplane acceleration increments is about 0.74, whereas the corresponding experimental ratio is about 0.56. Similarly, for the helicopter at 40 miles per hour and the airplane at 140 miles per hour, the calculated ratio is 0.38, while the measured value is approximately 0.24. Thus, in each case, a somewhat greater gust alleviation is indicated for the helicopter than for the airplane, the greater difference occurring at the lower helicopter speed.

Because of the substantial variation of helicopter acceleration with airspeed (contrary to the trend shown in fig. 2) that was encountered during these tests, additional flights were made at a later date by the helicopter in gusty air at several different airspeeds over the same ground path. Examination of the resulting accelerometer record (fig. 5) revealed a marked change in the acceleration level as airspeed was reduced. This change is particularly noticeable in the test in which the pilot started at 85 knots, gradually slowed down to 20 knots, and then returned to the original speed.

In order to evaluate these results more quantitatively, the number of acceleration increments encountered at each of several different levels and for each of the airspeeds were counted and are shown in table II. Although these data are insufficient for statistical purposes, the trend with respect to airspeed is evident and indicates that reducing the airspeed should be an effective method of reducing gust loads of helicopters. It may also be inferred that when gust-alleviation factors are specified forward speed may be a more important parameter than is indicated by the simply calculated curve shown in figure 2.

CONCLUDING REMARKS

The results of flight tests of a helicopter and an airplane flown side by side in rough air have indicated a somewhat greater gust alleviation for the helicopter than for the airplane, the greatest difference occurring at the lower helicopter speeds.

The effect of forward speed on the response of the helicopter to a given gust velocity was calculated by assuming the gust to produce only an angle-of-attack change of the rotor. These simply calculated values did not, however, agree with the measured results wherein the helicopter accelerations showed a substantial reduction as airspeed was reduced. Thus it appears necessary to use a more rigorous analytical approach

when it is important to predict more accurately the helicopter load factors due to a given gust.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 28, 1954.

REFERENCES

1. Donely, Philip: Summary of Information Relating to Gust Loads on Airplanes. NACA Rep. 997, 1950. (Supersedes NACA TN 1976.)

2. Amer, Kenneth B., and Gustafson, F. B.: Charts for Estimation of Longitudinal-Stability Derivatives for a Helicopter Rotor in Forward Flight. NACA TN 2309, 1951.
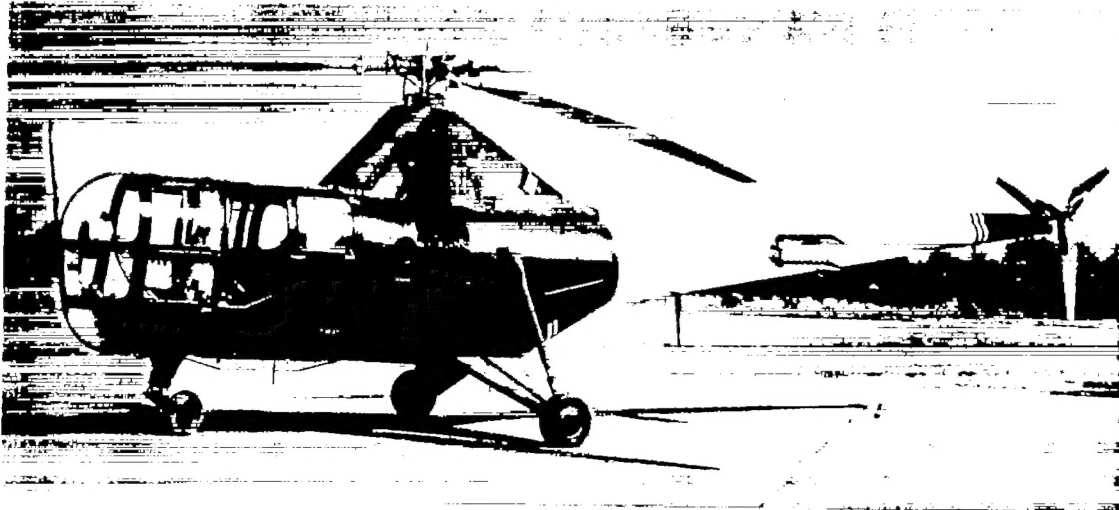
TABLE I

FREQUENCY DISTRIBUTION OF ACCELERATION INCREMENTS

Helicopter

Δa_n, g units	Number of acceleration increments at flight speed, mph, of -	
	40	80
0.06	26	33
.07	16	23
.08	11	40
.09	12	33
.10	7	33
.11	2	17
.12	1	16
.13	0	11
.14	0	13
.15	1	8
.16	-	6
.17	-	9
.18	-	1
.19	-	1
.20	-	1
.21	-	0
.22	-	1
.23	-	0
.24	-	0
.25	-	0
.26	-	0
.27	-	0
.28	-	0
.29	-	0
.30	-	0
.31	-	1
Air miles flown . .	7.5	19.0

Airplane

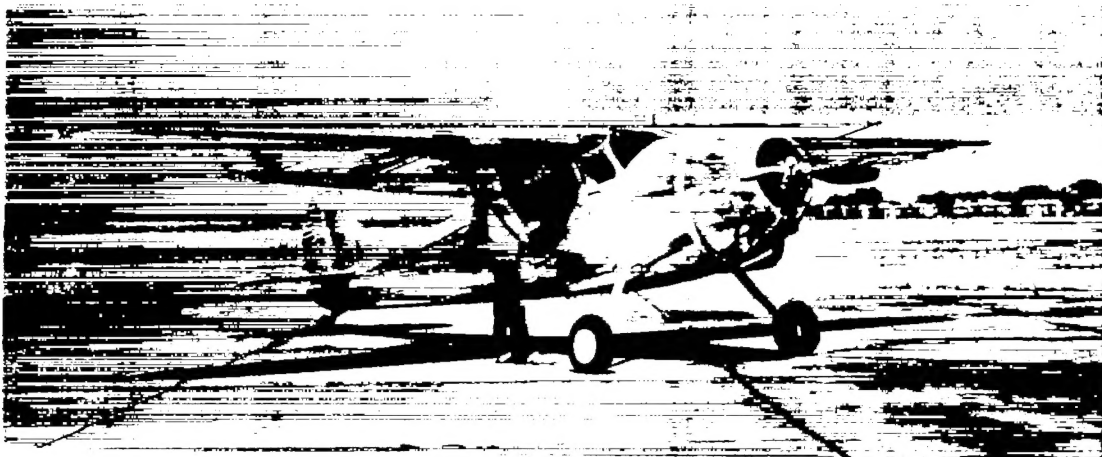| Δa_n, g units	Number of acceleration increments at flight speed, mph, of -	
	80	140
0.12	46	21
.14	76	42
.16	42	44
.18	37	46
.20	17	43
.22	26	48
.24	14	33
.26	10	38
.28	3	26
.30	4	17
.32	2	16
.34	0	27
.36	3	6
.38	0	9
.40	0	14
.42	1	7
.44	-	6
.46	-	9
.48	-	3
.50	-	3
.52	-	2
.54	-	1
.56	-	1
.58	-	0
.60	-	0
.62	-	1
.64	-	0
.66	-	1
.68	-	0
.70	-	1
Air miles flown . .	20.0	23.6

TABLE II

NUMBER OF ACCELERATION INCREMENTS ENCOUNTERED BY HELICOPTER

Range of Δa_n, g units	Number of acceleration increments encountered at flight speed, knots, of -					
	75	25	45	75	85 to 20 to 85	15
0.1 to 0.2	32	3	11	30	21	0
0.2 to 0.3	13	1	1	10	3	0
Over 0.3	0	0	0	1	0	0
Approximate air miles flown . . .	3.0	3.0	3.0	3.0	3.0	0.3

(a) Test helicopter.   L-70863

(b) Test airplane.   L-57649

Figure 1.- Aircraft used in investigation.

Figure 2.- Calculated acceleration increment per unit gust velocity for test airplane and helicopter.
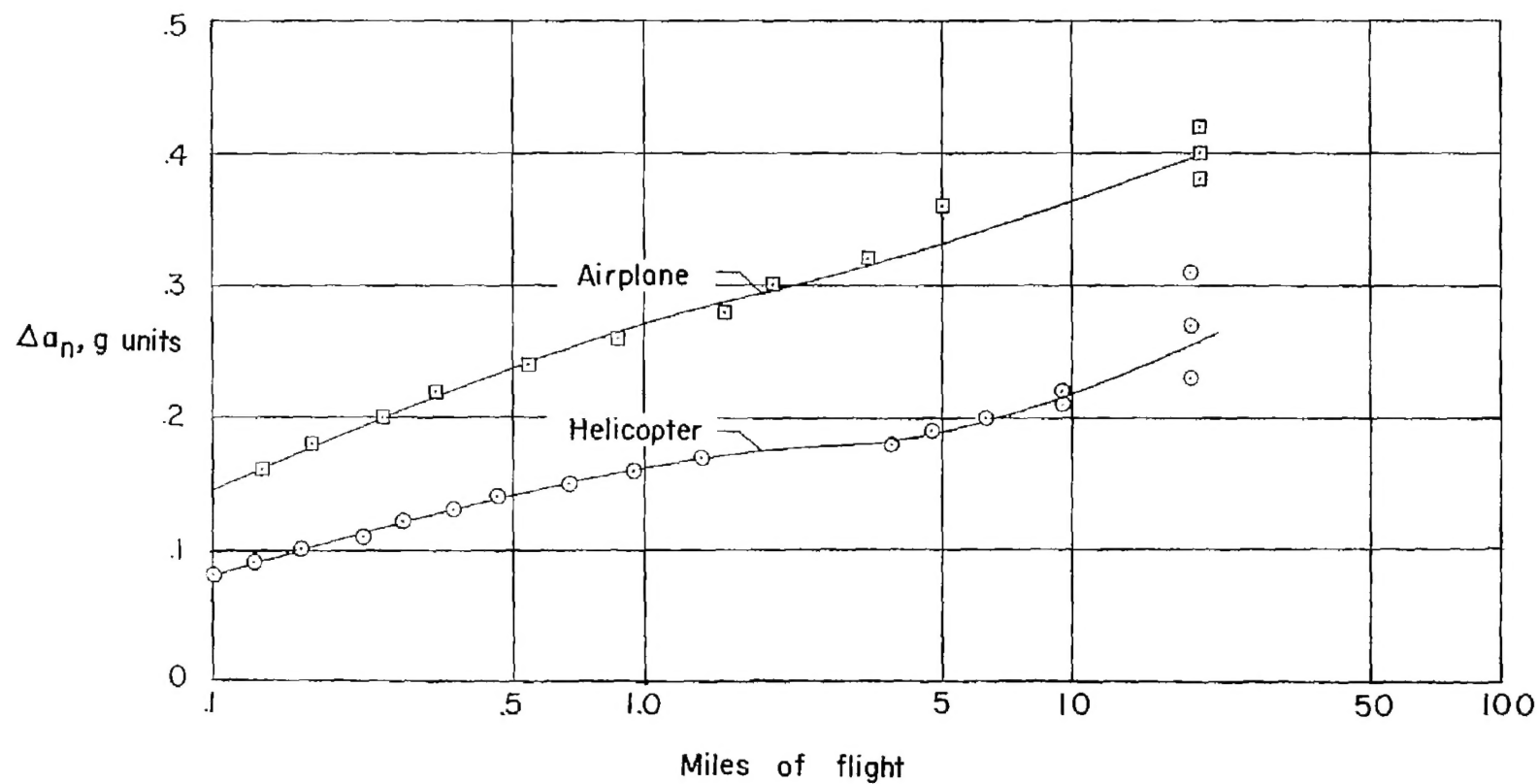
Figure 3.- Gust experience of helicopter and airplane at 80 miles per hour.
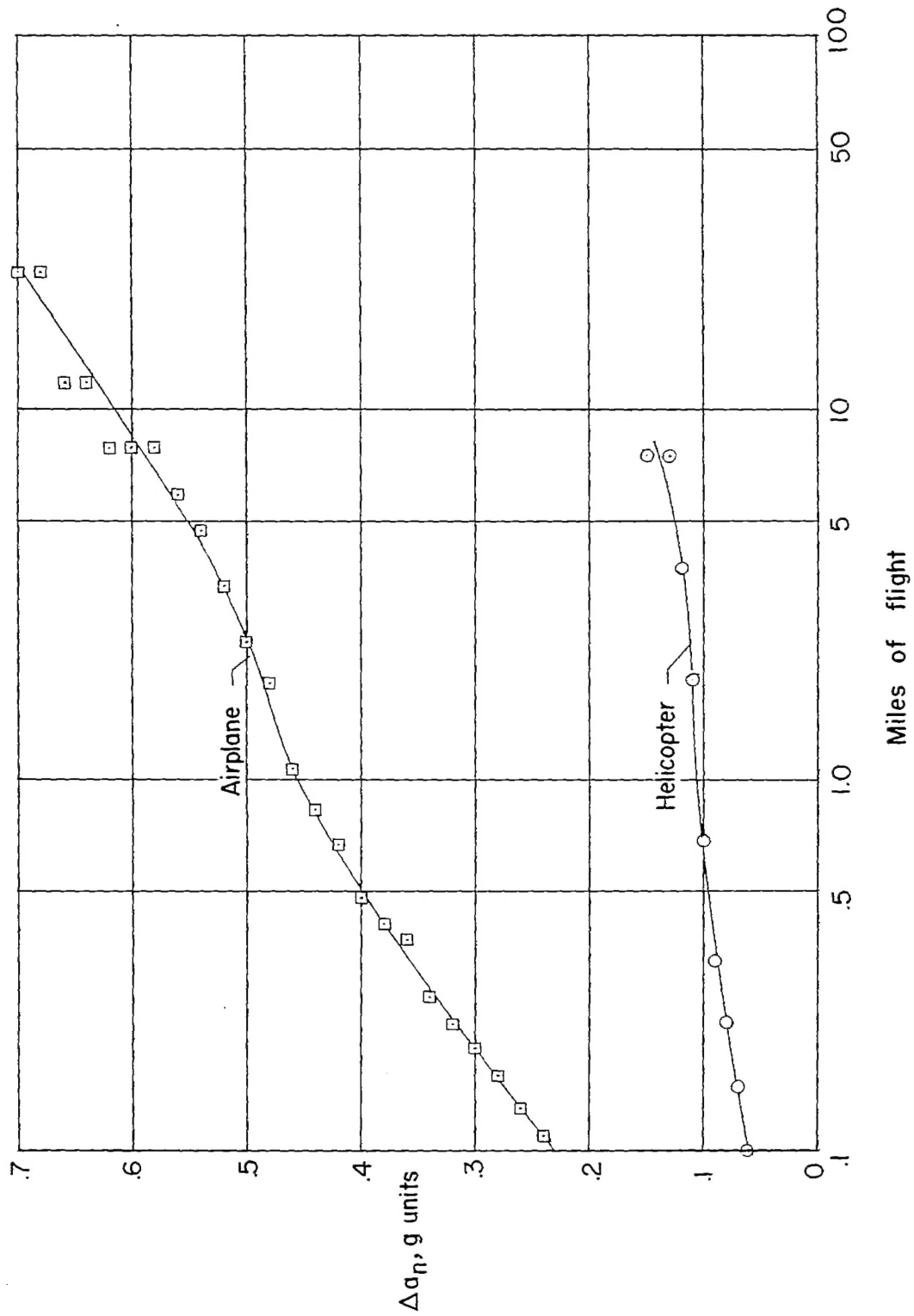
Figure 4.- Gust experience of helicopter at 40 miles per hour and airplane at 140 miles per hour.
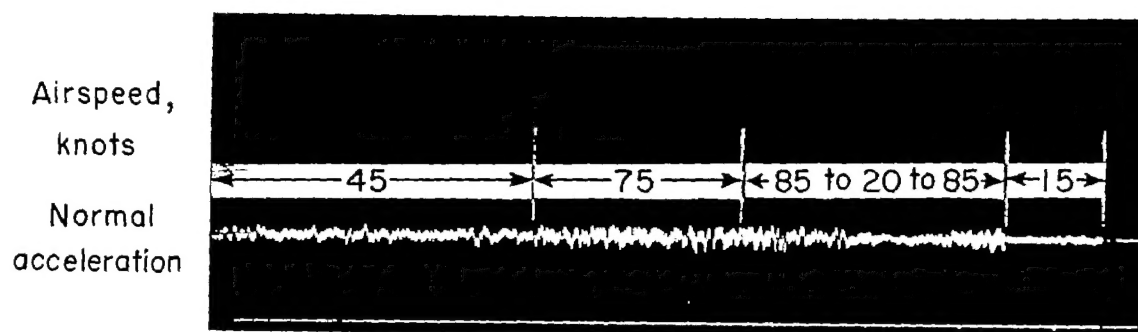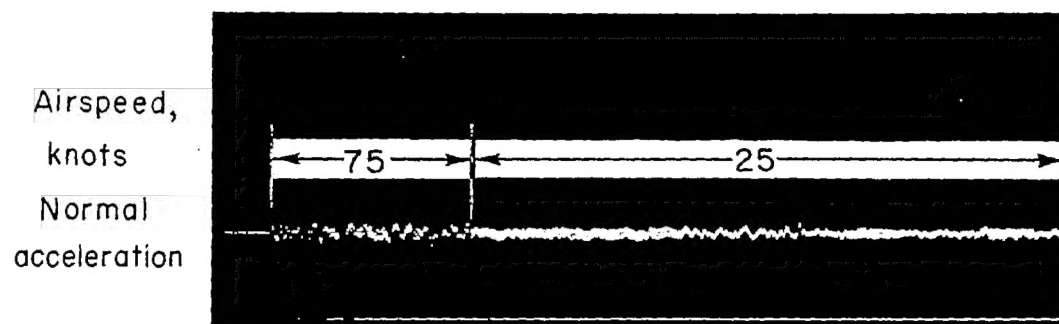
Figure 5.- Accelerometer record of helicopter flying in gusty air at various airspeeds.